AD-782 978

ANALYSIS OF DELIVERY ACCURACY FOR AH-1G (COBRA) LAUNCHED 2.75-INCH ROCKETS FROM TESTS CONDUCTED JANUARY-MARCH 1972 AT CHINA LAKE, CALIFORNIA

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May 1974

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SAO Report 3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD 782 978
4. TITLE (and Subtitle) ANALYSIS OF DELIVERY ACCURACY FOR AH-1G (COBRA) LAUNCHED 2.75-INCH ROCKETS FROM TESTS CONDUCTED JANUARY-MARCH 1972 AT CHINA LAKE, CALIFORNIA		5. TYPE OF REPORT & PERIOD COVERED Technical Report June 1973 to August 1973 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Walter J. Baumen, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander, US Army Armament Command Attn: AMSAR-SA Rock Island, Illinois 61201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Commander, US Army Armament Command Attn: AMSAR-SA Rock Island, Illinois 61201		12. REPORT DATE May 1974 13. NUMBER OF PAGES 30
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AH-1G (COBRA) Rocket	2.75-Inch Rocket	Experienced pilots	LOS-transform
Pass-to-pass bias	Slant ranges	Nonexperienced pilots	Trajectory transform
Ripple-to-ripple bias	Pitch	Pilot learning	Fixed bias
Round-to-round error	Deflection	Variable bias	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The accuracy of the AH-1G (COBRA)/2.75-Inch Rocket system was determined. Results are -9.4 mils in pitch, 9.3 mils in deflections for pass-to-pass variable bias. The values 9.1 mils (at 3000 meters) to 20.6 mils (at 1300 meters) in pitch, and 9.9 mils in deflection apply to ripple-to-ripple variable bias. For round-to-round error, the values 7.6 to 10.0 mils in pitch and 8.7 to 11.3 mils in deflection are given. These values are given for the attack slant ranges between 1300 and 3000 meters. They are for experienced pilots. The effect of experience on accuracy of pilots is given for this rocket system.

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SUMMARY

The objective of this study was to determine the operational delivery accuracy of the AH-1G (COBRA)/2.75-Inch Rocket System through analysis of data from Phase C of the Baseline Accuracy Test Program. A secondary objective was to investigate the differential effects on accuracy due to pilot experiences, adjustments of aim in the process of attack and pilot learning due to multiple attacks against the same target.

Delivery error was defined in terms of three distributions: (a) the distribution of pass-to-pass variable bias, (b) the distribution of ripple-to-ripple bias, and (c) the distribution of round-to-round error. Estimates of the standard deviations characterizing these distributions were derived. These estimates, applicable to attack slant ranges between 1300 and 3000 meters are:

a. For pass-to-pass variable bias; 9.4 mils in pitch, and 9.3 mils in deflection.

b. For ripple-to-ripple variable bias; 9.1 mils (at 3000 meters) to 20.6 mils (at 1300 meters) in pitch, and 9.9 mils in deflection.

c. For round-to-round error; 7.6 to 10.0 mils in pitch, and 8.7 to 11.3 mils in deflection.

These estimates apply to rocket delivery by experienced pilots. Analogous estimates applicable to nonexperienced pilots are statistically slightly higher but for practical purposes the same as those given above. The essential differences among pilot groups are:

a. Pass-to-pass learning resulting from multiple attacks against the same target results in progressively smaller delivery error only in cases of experienced pilots at close (less than 2000 meters) range.

b. Fixed biases of nonexperienced pilots are significantly larger than those of experienced pilots.

c. Successful aim adjustment over successive ripples launched in a given attack can be accomplished only by experienced pilots.

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PREFACE

This study was authorized by the Director, US Army MUCOM Operations Research Group, pursuant to a program for general systems analysis support requested by the Project Manager for the 2.75-Inch Rocket System.

This task was part of a study program to quantify operational delivery accuracy of the currently configured AH-1G (COBRA)/2.75-Inch Rocket System and to determine the relative on-target effectiveness benefits of fire control for helicopter-rocket systems. These analyses relate to delivery accuracy. Further analyses based on estimates originating in this report and related to on-target effectiveness are contained in ARMCOM SAO Report "Comparative Effectiveness and Rocket Expenditures of Selected AH-1G (COBRA/2.75-Inch Rocket System (U)", September 1973, CONFIDENTIAL.

This report has been prepared from the standpoint of providing a record of the rationale and scope of the analytical effort as well as the information derived thereform. Work was begun in June 1973 and completed in August 1973. Essential results were transmitted to the Office of the Project Manager in the course of analysis. Study was completed by the US Army MUCOM Operations Research Group. Finalization of the study report was accomplished by its successor, the ARMCOM Systems Analysis Office.

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INTRODUCTION

OBJECTIVE

1. The primary objective of these analyses was to determine the operational delivery error budget for the currently configured AH-1G/2.75-Inch Rocket System. Subordinate objectives were to determine the effects on accuracy due to pilot learning over successive passes at the same target, pilot experience, and aim adjustment over successive ripples launched during a given pass.

BACKGROUND

2. The Project Manager for the 2.75-Inch Rocket System initiated the Baseline Accuracy Test Program to identify and quantify components of helicopter/rocket delivery error and to determine the operational delivery accuracy of the currently configured AH-1G/2.75-Inch Rocket System. The test program consisted of three phases, denoted A, B, and C. Tasked by the Project Manager, the Ammunition Development and Engineering Directorate (SARPA-AD-D), Picatinny Arsenal, Dover, New Jersey, identified and quantified error components using data from phases A and B. The Project Manager subsequently requested the MUCOM Operations Research Group to quantify operational accuracy of the AH-1G/2.75-Inch Rocket System. In fulfilling this objective, use was made of data from Phase C[1] of the Baseline Tests, along with summarized estimates of inherent rocket dispersion from Phase B data analyzed by Picatinny Arsenal.

SUMMARY OF TEST CONDITIONS

3. Rocket impact coordinates used as the basis for analyses summarized herein were obtained by processing the published flight test data for Phase C of the Accuracy Tests. The Phase C test utilized an AH-1G/2.75-Inch Rocket System with standard MK40 motors and XM230 practice warheads. Test firing procedure consisted of the firing of up to four pairs of rockets per pass by each of the fourteen pilots at nominal slant ranges of 1000, 2000, and 3000 meters. Two passes were executed by each pilot at each nominal range. The initial pass for all pilots was at the nominal range of 2000 meters. The time between launch of pairs and the number of rockets per pass were the pilot's option. The pilot was restricted only by the instructions to launch rockets in pairs (i.e., one rocket simultaneously from each of two pods) and to maintain an altitude of less than 500 feet. Each pilot was vectored by radar into the firing zone and was released to fire upon identification of the target. Aircraft position and velocity at launch were measured by radar. Impacts over the target area were recorded on film by an overflying aircraft. Attack geometries used in the test are summarized in Table 1.

TABLE 1. Attack Geometries Used in Phase C of the Baseline Accuracy Tests

NOMINAL SLANT RANGE (meters)	AVERAGE LAUNCH CONDITIONS				NO. PAIRS
	Slant Range (meters)	Alt (ft)	LOS* (degrees)	Velocity (kts)	
1000	1322	435	5.8	99	106
2000	2065	485	4.1	95	97
3000	2905	560	3.4	95	94

* Line of sight angle from target to launch point.

APPROACH

ASSUMPTIONS

4. The following assumptions governed the analysis of accuracy data:

a. During testing, the pilots attempted to adjust fire toward the target center by observing the rockets burning in-flight, making estimates regarding their expected points of impact, and offsetting the aim point (i.e., the sight reticle and the target) accordingly.

b. Test conditions from pilot to pilot were sufficiently similar to preclude introduction of appreciable nonrandom bias.

c. When projected into the plane normal to the line of sight and converting to angular measure, the mean points of impact (MPI) of pairs of rockets are normally distributed in both pitch and deflection.

d. When statistical tests indicate no significant effect of flight profiles on accuracy, associated estimates can be combined, via statistical pooling, into a composite estimate applicable to all the component profiles.

e. Impact dispersion about the ripple mean point of impact (MPI) is dependent on the number of rockets in the ripple. However, aiming errors are independent of ripple size.

f. During the test, pilots were not given range information, and the range-estimation error, included here within aiming error, is representative of that encountered in the operational environment.

MEASURES OF DELIVERY ERROR

5. The following measures of delivery error were employed in the analysis:

a. Fixed bias – The deviation between the overall mean point of impact (MPI) and target center is interpreted as an estimate of fixed bias.

b. Pass-to-pass variable bias – Variability of this error is defined by standard deviation of individual-pass MPIs about the fixed bias and is denoted by σ_1. Associated errors represent deviations between an individual-pass MPI and target center which are constant in effect for all ripples of any one firing pass, but which vary in magnitude from pass to pass. Pilot aim variation over passes is included in σ_2.

c. Ripple-to-ripple variable bias – Variability of this error is defined as the standard deviation of ripple MPIs about the pass bias and is denoted by σ_2. Associated errors represent deviations between an individual-ripple MPI and the pass MPI which are constant in effect throughout any one ripple, but which vary in magnitude from ripple to ripple.

d. Round-to-round dispersion – Variability of this error is defined by the standard deviations of impacts about the ripple MPI and is denoted by σ_3. The magnitude of this error varies from round to round. Analysis of Phase B test data by Picatinny Arsenal showed σ_3 to be dependent on ripple size. Since Phase C was restricted to ripples of size two, estimates of σ_3 from Phase B were provided by Picatinny Arsenal so that more general cases could be represented.

DATA ANALYSIS PROCEDURE

6. Errors were converted to angular measure by two methods, denoted by the line-of-sight (LOS) transform and by the trajectory transform. The former is the more conventional method of processing pitch errors. However, while suitable for internal analysis of data, it does not have general predictive utility because it does not normalize over attack angle. The trajectory-transform method does normalize accuracy results over attack angle and allows generalization of angular error estimates to attack geometries other than those employed in the test. The methods of translation of error from ground miss distances into angular deviations are presented in Appendix A.

7. Estimates of system errors were formed by pooling subestimates based on different flight profiles and conditions. Therefore, the analysis of differential effects of the flight profile upon accuracy was necessary for determining overall accuracy. The test data were partitioned into two groups, based on firings by experienced (EXP) and on firings by nonexperienced (NONEXP) pilots. Placement into a pilot experience group was determined by the previous number of rockets fired by each pilot. Composition of these groups is shown in Appendix B. Within each pilot group, data was further categorized by pass sequence and nominal slant range. Accuracy estimates were computed, compared and, if applicable, combined (pooled) from these categories.

8. The basic "building blocks" for accuracy estimates were the ripple-to-ripple variable-bias standard deviation (σ_2) and the mean MPI for each pass-pilot combination of the test. These basic data are shown in Appendix B.

9. Initially, composite accuracy estimates, pooled over pilots within each experience group, were determined for each pass at each nominal range. Statistical comparisons were made to assess accuracy differences over passes. Where no significant difference over pass sequence was found, composite (pooled) accuracy estimates, applicable to all passes at each range, were formed. Pitch accuracy estimates were then normalized over attack angle by converting them to trajectory-transform errors. Statistical comparisons were then made with accuracy estimates over different nominal slant ranges and, where no significant differences were found, composite estimates were formed which were considered applicable to all slant ranges encompassed by the test data. Final accuracy estimates consisted of composite first-pass estimates for the experienced-pilot group with fixed bias excluded. Accuracy components quantified were σ_1 (standard deviation of pass-to-pass bias), and σ_2 (standard deviation of ripple-to-ripple bias). In addition, estimates are given for σ_3, the standard deviation of round-to-round dispersion. Statistical pooling formulas applied are shown in Appendix B.

10. The following statistical tests were used, as indicated, in analyzing the accuracy data. A 0.05 significance level (rejection criterion) was used in applying each test.

a. The Student T test[2] – This was used for assessing difference between sample means to compare fixed-bias estimates.

b. The Snedecor F test[3] – This was used for comparing two standard deviations to analyze differences in σ_1 and σ_2 due to pass sequence (learning) or to pilot experience.

c. The M test[4] – This was used for assessing homogeneity in a group of sample standard deviations to analyze difference in σ_1 and σ_2 over varying nominal attack ranges.

d. The Central Limit Theorem, as applied to a proportion[5] – This was used to analyze aim (MPI) adjustment over successive pairs.

e. The Kolmogorov-Smirnov test[6] – This was used to assess the deviation from normality of the distributions associated with σ_2. No significant deviations from normality were found, thus lending credence to the use and applicability of statistical tests requiring normal distributions for validity.

RESULTS AND DISCUSSION

ERROR VARIATION OVER PASS SEQUENCE

11. The first step leading to formulation of the system error budget was a comparison of accuracy estimates over firing-pass sequence to determine whether pooled composite estimates were applicable to both passes at each nominal slant range. A reduction of error with pass sequence could be induced by learning effects due to increasing familiarity with the flight profile environment.

12. Estimates of pass-to-pass variable-bias σ_1 and estimates of fixed bias are shown in Table 2 by pass sequence. No significant differences over passes exist in the nonexperienced pilot group. For experienced pilots, the only statistically significant difference exists in the pitch dimension at 1000-meter nominal range. In this case, σ_1 of the first pass exceeds that of the second pass. Similarly, comparisons of fixed bias over pass show a significant difference with pass sequence only for experienced pilots, in pitch at 1000 meters. The average second-pass fixed bias is generally less in absolute magnitude than that for the first pass. These differences suggest learning; however, the tendency is not statistically significant in the cases of 2000- and 3000-meter nominal range.

13. The σ_2 (ripple-to-ripple variable-bias) accuracy estimates are displayed in Table 3 according to pass sequence. There are no statistically significant differences in σ_2 over passes in the nonexperienced pilot group. For experienced pilots, the only significant differences are in pitch at nominal ranges of 1000 meters and 2000 meters. In these cases, σ_2 estimates for the second pass are smaller than those for the first pass.

TABLE 2. Standard Deviation (σ_1) of Pass-to-Pass Variable Bias About the Mean Bias by Sequence of Pass

PILOT GROUP	NOMINAL RANGE (m)	ORDER OF PASS	PASS-TO-PASS VARIATION σ_1		FIXED PITCH	BIAS DEFL (mils)	SAMPLE SIZE*
			Pitch (mils)	Deflection (mils)			
EXP	1000	First	7.24	11.66	-4.88	4.40	9
		Second	3.14	6.89	2.25	.92	9
	2000	First	5.75	9.37	-2.16	.59	9
		Second	4.18	10.65	1.86	1.72	9
	3000	First	3.45	7.54	-.79	1.54	8
		Second	3.34	8.59	.73	.26	9
NONEXP	1000	First	6.36	3.78	6.33	12.68	5
		Second	9.77	15.31	-1.03	7.52	5
	2000	First	5.54	14.62	2.97	13.27	4
		Second	6.25	4.69	5.68	12.72	5
	3000	First	3.46	14.75	-2.21	12.96	5
		Second	5.16	18.72	-1.05	10.84	5

* Number of passes in the sample.

TABLE 3. Standard Deviation (σ_2) of the Ripple-to-Ripple Variable Bias by Sequence of Pass

PILOT GROUP	NOMINAL RANGE (m)	ORDER OF PASS	RIPPLE-TO-RIPPLE VARIATION σ_2		NO. OF PAIRS
			Pitch (mils)	Deflection (mils)	
EXP	1000	First	16.02	10.14	33
		Second	9.49	10.98	36
	2000	First	7.61	11.33	33
		Second	4.59	10.14	34
	3000	First	3.06	7.32	28
		Second	3.10	7.39	32
NONEXP	1000	First	10.92	8.48	19
		Second	11.28	8.97	18
	2000	First	7.72	10.77	12
		Second	6.50	7.12	18
	3000	First	3.25	8.00	15
		Second	5.62	13.45	17

14. Accuracy estimates obtained by pooling (to the extent permitted by statistical tests) are shown in Table 4. Where a single estimate is shown, data could be pooled into a composite value independent of pass. It should be noted that pooling over range can be accomplished only in the case of deflection.

TABLE 4. Composite (Pooled) Accuracy Estimates Applicable to All Firing Passes

PILOT GROUP	ERROR COMPONENT	SLANT RANGE (m)	MAGNITUDE OF ERROR (mils)	
			Pitch	Deflection
EXP	σ_1: Pass-to-pass variable bias	1350	b	9.50
		2100	5.03	10.00
		2900	3.39	8.12
		1350-2900	a	9.30
	σ_2: Ripple-to-ripple variable bias	1350	b	10.60
		2100	b	10.74
		2900	3.08	7.36
		1350-2900	a	9.90
	Mean MPI: Fixed bias	1350	b	2.58
		2100	-.09	1.17
		2900	.12	.33
		1350-2900	a	1.40[c]
NONEXP	σ_1: Pass-to-pass variable bias	1300	8.24	11.15
		2050	5.96	10.21
		2900	4.39	16.85
		1300-2900	a	13.18
	σ_2: Ripple-to-ripple variable bias	1300	11.10	8.72
		2050	6.99	8.70
		2900	4.70	11.31
		1300-2900	a	9.60
	Mean MPI: Fixed bias	1300	2.75	10.17
		2050	4.59	12.94
		2900	-1.59	11.83
		1300-2900	a	11.55

[a] Range dependent; cannot be pooled over range

[b] Pass dependent; cannot be pooled over pass.

[c] Includes MPI result for two single-pair firings which were not suitable for other estimates.

ERROR VARIATION OVER RANGE

15. The second step toward formation of an error budget was a statistical comparison of accuracy estimates over nominal attack ranges to determine whether composite estimates applicable to all test ranges could be formed. Statistical tests of homogeneity indicated deflection estimates of Table 4 to be independent of target slant range, thus justifying their pooling into a composite estimate for each pilot group. Pitch-error standard deviations from Tables 2, 3, and 4 were statistically heterogeneous over range, showing a tendency to decrease with increasing slant range. This dependence is chiefly due to the influence of changing attack angle with range, in conjunction with the use of line-of-sight (LOS) transform errors in pitch. As explained in Appendix A, the LOS transformation of pitch error is dependent on attack angle because it implicitly approximates the trajectory by a straight line.

16. Normalization over attack angle was performed on the pitch-error estimates of Tables 2, 3, and 4 by converting them to trajectory-transform pitch errors, which are angular deviations of trajectory quadrant elevations. Results appear in Table 5. After normalization, the first-pass σ_2 pitch estimates and the second-pass σ_1 estimates for experienced pilots are the only instances of residual dependence on slant range. This dependence is in part attributable to learning since the test conditions generally had target slant ranges in the same firing sequence for all pilots. The nominal target ranges for the first three test passes were generally 2000 meters, 1000 meters and 3000 meters, respectively. The succeeding three passes had the same order of target ranges. Thus, a learning factor which was transferable over target range could have caused smaller first pass errors at 3000 meters. In such an instance, the first-pass test error estimates at 1000 meters and 2000 meters might be more representative of actual operational conditions.

OPERATIONAL SYSTEM-ERROR BUDGET

17. Using composite accuracy estimates derived from the preceding sections, integration with round-to-round dispersion values yielded an error budget for operational accuracy of the AH-1G/2.75-Inch Rocket System. The resultant estimates were based on first-pass conditions disregarding fixed bias. The implied total-system error budget was derived from estimates in Tables 2, 3, 4, and is presented in Table 6 and Figure 1. All pitch errors are trajectory transformed; therefore, they are normalized over attack angle. Estimates for round-to-round dispersion were provided by Picatinny Arsenal Ammunition Development and Engineering Directorate (SARPA-AD-D), Picatinny Arsenal, Dover, New Jersey from analysis of Phase B baseline data.

18. Use of Figure 1 to obtain σ_2 pitch estimates is necessitated by the residual dependence on slant range after normalization for attack angle. As noted earlier, this is probably due to learning acquired during the first sequence of firing in the test.

ACCURACY DIFFERENCES DUE TO EXPERIENCE

19. While the experienced pilot group served as the basis for final operational-system accuracy estimates, a subordinate study purpose was to assess accuracy differences due to varying experience. Such examination could reveal areas in which incorporation of improved fire-control

TABLE 5. Angular Estimates of Error Components in Pitch Derived from Trajectory Transform

PILOT GROUP	ERROR COMPONENT	SLANT RANGE (m)	MAGNITUDE OF ERROR (mils)		
			First Pass	Second Pass	Pooled
EXP	σ_1: Pass-to-pass variable bias	1350	9.3	3.9	a
		2100	10.3	7.5	9.0
		2900	10.2	9.8	10.0
		1350-2900	9.4	b	–
	σ_2: Ripple-to-ripple variable bias	1350	20.6	11.8	a
		2100	14.0	8.0	a
		2900	9.0	9.1	9.1
		1350-2900	b	9.7	–
	Mean MPI: Fixed bias	1350	-6.3	4.8	a
		2100	-3.9	3.3	-.2
		2900	-2.3	2.1	.3
		1350-2900	-4.2	3.4	
NONEXP	σ_1: Pass-to-pass variable bias	1300	7.9	12.1	10.2
		2050	9.6	10.8	10.3
		2900	9.9	14.8	12.6
		1300-2900	9.1	12.7	11.1
	σ_2: Ripple-to-ripple variable bias	1300	13.6	14.0	13.8
		2050	13.3	11.2	12.1
		2900	9.3	16.1	13.5
		1300-2900	12.2	13.8	13.2
	Mean MPI: Fixed bias	1300	7.9	-1.3	3.4
		2050	5.1	9.8	7.9
		2900	-6.3	-3.0	-4.6
		1300-2900	2.0	-1.8	-2.0

[a] Pass dependent; cannot be pooled.

[b] Range dependent; cannot be pooled.

TABLE 6. Operational Delivery Error Estimates for the AH-1G/2.75-Inch Rocket System

ERROR COMPONENT	RIPPLE SIZE (Pairs/Ripple)	STANDARD DEVIATION (mils)	
		Pitch[a]	Deflection
σ_1: Pass-to-pass variable bias	All	9.4	9.3
σ_2: Ripple-to-ripple variable bias	All	9.1-20.6[b]	9.9
σ_3: Round-to-round dispersion	4	7.6	8.9
	7	7.3	8.7
	19	10.0	11.3

[a] Pitch errors based on trajectory intercept in perpendicualr plant; deflection errors based on line-of-sight intercept.

[b] Range dependent; see Figure 1 for evaluation. The composite pooled estimate over this interval is 15.5 mils.

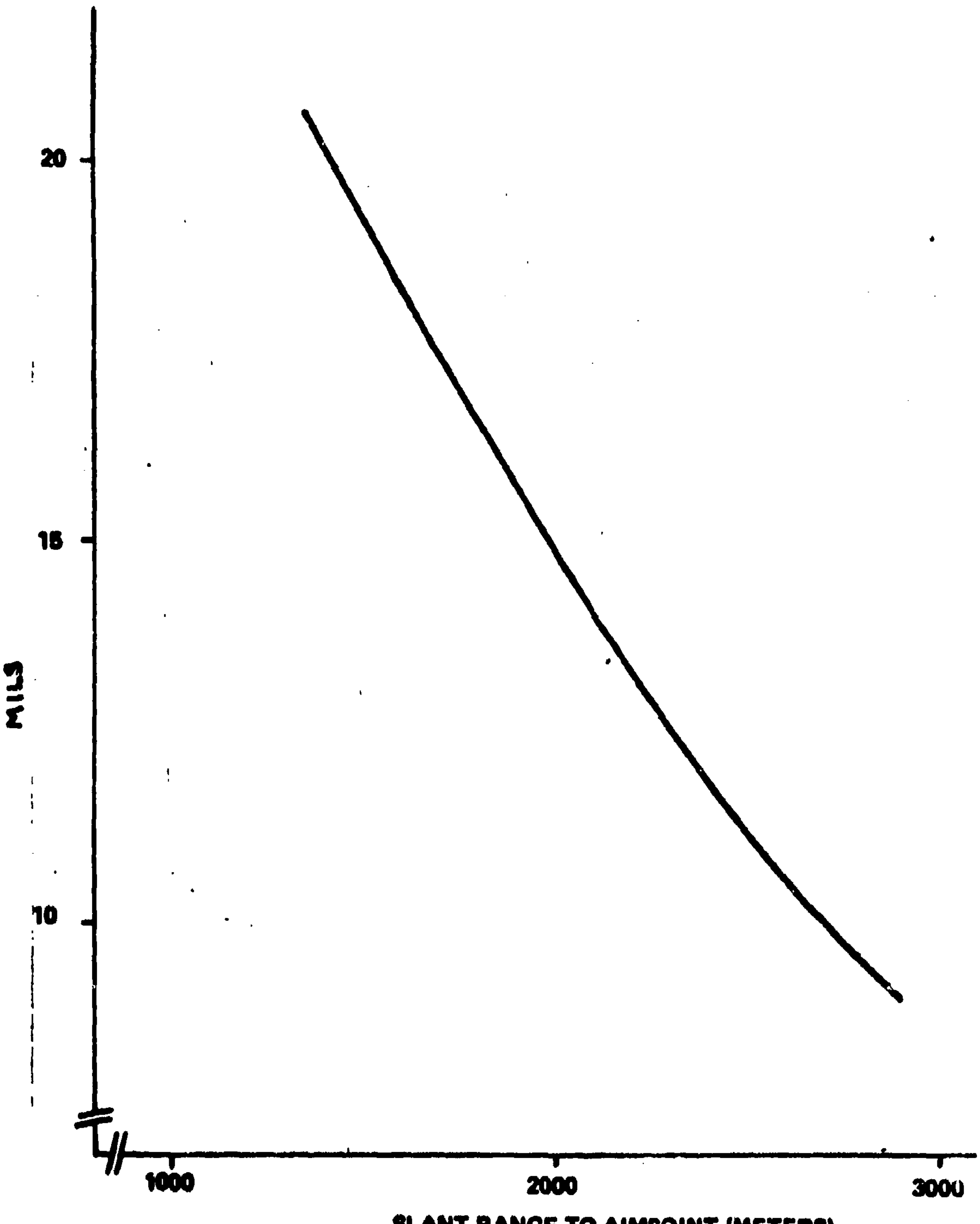

FIGURE 1. Operational Delivery Error – Standard Deviation (σ_2) of Ripple-to-Ripple Variable-Pitch Bias

systems might be especially useful as a substitute for certain aiming skills learned otherwise through practice or trial and error. The data of Tables 2, 3, and 4 were used to compare pilot experience groups with statistical tests.

20. The pooled composite σ_2 deflection estimates were not significantly larger for the nonexperienced group. First-pass σ_2 estimates in pitch were larger for experienced pilots at 1000 meters, not significantly different at 2000 meters, and significantly smaller at 3000 meters than corresponding estimates for nonexperienced pilots.

21. The pooled fixed-bias estimates in pitch for nonexperienced pilots were significantly larger than for experienced pilots at 1000 meters and 2000 meters, but were not significantly different at 3000 meters. In deflection, overall fixed bias for the nonexperienced group was significantly larger than that for the experienced group and showed a strong tendency to hit to the right of the target. The overall deflection fixed bias for experienced pilots was not significantly different from zero. That for the nonexperienced group was significantly greater than zero. Thus, in operational terms, these data indicate that the major benefit of experience is the ability to correct for deflection relative wind and keep the MPI on the target.

ADJUSTMENT OF AIM DURING ATTACK

22. If the pilot can adjust fire successfully, the angular separation distances of the MPI and the target will decrease with successive pairs of rockets launched during the attack. For each nominal range and pilot group, all angular deviations of consecutively fired pair MPIs were compared to determine those instances in which the second (successive) MPI was closer to the target. This enumeration yielded the data of Table 7. Enumerated instances were converted to relative frequencies which served as estimates for the probability of successful (closer) aim adjustment between pairs.

TABLE 7. Sample Probabilities of Successful MPI[a] Adjustment Over Consecutive Ripples[b]

PILOT GROUP	NO. MPI PAIRS	PROBABILITY ADJ. MPI[c] IS CLOSER	
		Pitch	Deflection
EXP	143	.51	.59
NONEXP	69	.54	.48

[a] MPI locations were defined by angular units (mils) in the plane perpendicular, at target, to the line of sight.

[b] Analysis was for all consecutively fired pairs from Phase C of the Baseline test.

[c] "Adj. MPI" denotes the second MPI of a consecutive pair.

23. If only random adjustment occurred between pairs, the adjusted MPI should theoretically have no more than a 50 percent chance of being closer to the target. A probability of greater than 50 percent would be consistent with successful aim adjustment. Since most probabilities displayed in Table 7 are not significantly different from .50 in a statistical sense, random adjustment prevails. However, there is an exception in deflection results for the experienced pilots, which show an overall successful adjustment probability of .59. This sample probability is significantly greater than .50.

24. Further analysis was conducted with the experienced pilot group to determine whether time between firings of successive pairs was related to the likelihood of successful adjustment or not. The data for successive pairs were divided into two categories, based on the inter-pair firing interval. Associated probabilities of successful aim adjustment are shown in Table 8. Results indicate significant success in deflection aim adjustment for pair firings separated by intermediate time intervals of 1.05 to 1.65 seconds. However, firings separated by shorter or longer intervals showed only random (≈ .50) probability of successful adjustment in aim. Pitch adjustment was not significantly different from random in either firing-interval category.

TABLE 8. Effect of Time Between Ripples[a] on Probability of Successful MPI Adjustment – Experienced Pilots

TIME BETWEEN RIPPLES (sec)	NO. MPI PAIRS	PROBABILITY ADJ. MPI IS CLOSER	
		Pitch	Deflection
1.05 - 1.65	70	.57	.67
<1.05[b] or >1.65	73	.45	.52

[a] Obtained from trigger pulse generator measurements recorded during the test. A firing point is a time at which ripple fire was initiated. Precision of measurement was estimated at 1/60 of a second, but final data were tabulated only to the nearest 1/10 of a second.

[b] The shortest record time interval between consecutive pairs in Phase C was .8 second. The longest was 6.2 seconds.

CONCLUSIONS

25. Effects on accuracy due to learning over passes appear to be significant only in a small portion of the sample data, and then only in the pitch dimension. Test procedures which generally used a fixed sequence of firing ranges in the data studied, may have introduced learning effects into final estimates.

26. The major accuracy difference demonstrated between experienced and nonexperienced pilots was in fixed bias, with the nonexperienced-group bias being significantly larger, especially in deflection. In addition, analysis of effects of aim adjustment during attack showed only random

adjustment from pair-to-pair for nonexperienced pilots while experienced pilots demonstrated successful aim adjustment.

27. The best estimates of operational AH-1G/2.75-Inch Rocket Systems accuracy are those based on data for experienced pilots. These estimates, obtained by pooling applicable data from the test, are presented in summary form in Table 6 and Figure 1. Residual dependence of one error component on attack range was chiefly attributed to learning over a fixed firing-range sequence.

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APPENDIX A

ERROR TRANSFORMATIONS

LINE-OF-SIGHT TRANSFORM

A-1. As processed by the China Lake Naval Weapons Center, all ground plane test data were transformed into angular (mil) error in the following ways:

a. Errors of the MPI. The ground miss distances were projected, using lines of sight, into the plane perpendicular at the target to the line of sight (LOS). The subtended angular separation of the LOS intercepts in this plane was the associated angular error. A diagrammatic representation is shown in Figure A-1.

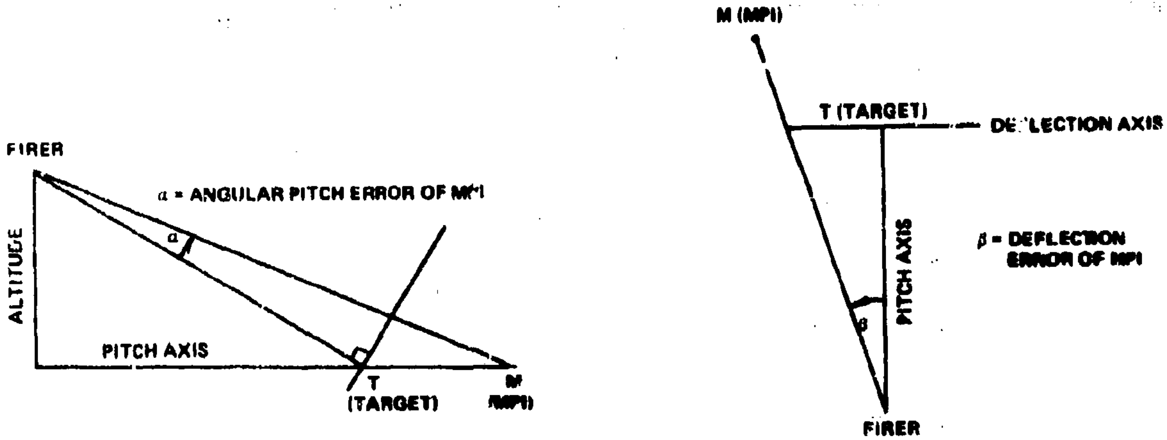

FIGURE A-1. Line of Sight Transformation of Error of the MPI

b. Errors of impacts about the MPI. The procedure was the same as above except that the projection plane was perpendicular at the MPI to the LOS from firer to MPI. A diagrammatic representation is given in Figure A-2.

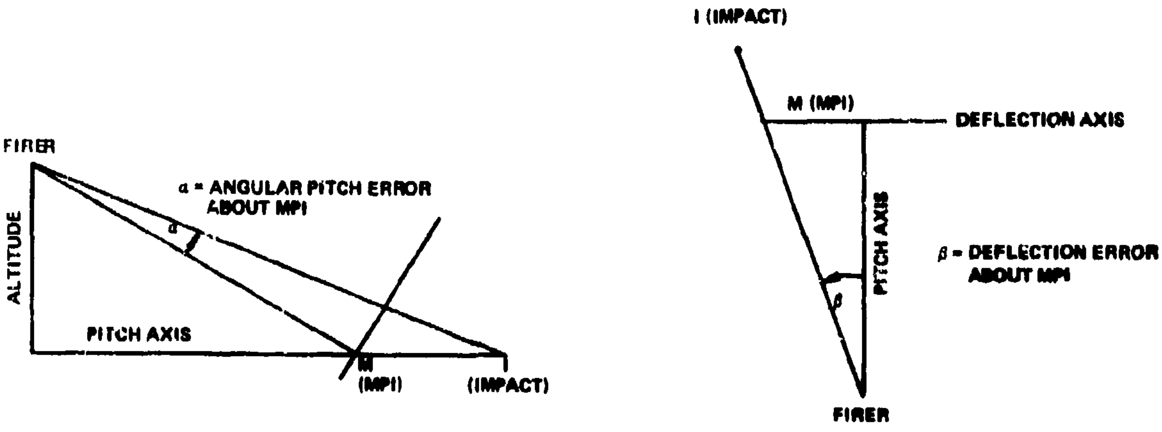

FIGURE A-2. Line of Sight Transformation of Error About the MPI

A-2. In the case of pitch errors, the above procedure, called the LOS transform, is often unsuitable for generalization of derived values to other attack geometries because it does not normalize over attack angle. This occurs because a straight line (the LOS) is used as the line of projection from the ground, whereas the warhead trajectory should be the line of projection. The normalized (over attack angle) pitch errors should therefore be based on subtended angles of trajectory intercepts in the perpendicular plane, not LOS intercepts. The corresponding angular errors would then be in terms of deviations of trajectory quadrant elevations, not lines of sight. The LOS transform is implicitly a technique which approximates the trajectory by the LOS. It is adequate for processing data based on high attack angles because the LOS and trajectory intercepts in the perpendicular plane are close together in such cases. However, for low attack angles, such as employed in Phase C of the baseline tests, the LOS transform and trajectory-transform methods frequently give widely disparate values. Application, via ground projection, of LOS-transform angular errors at low angles allows impossibly large projected ground-miss distance because gravity effects, implicit within a trajectory, are disregarded. However, as long as analysis is restricted to the test-firing conditions (attack geometry, etc.) used to derive them, the LOS-transform errors, being "equivalent" to ground errors, are meaningful.

RATIONALE FOR A TRAJECTORY-TRANSFORM TECHNIQUE

A-3. The most nearly rigorous method of converting ground-plane pitch errors into trajectory-transform angular errors is to generate a trajectory for every miss-distance case. This is considerably more tedious than the relatively simple trigonometric formulas defining the LOS transform. Compounding the above is the need to use similar trajectory generation in any on-target effectiveness model utilizing such errors. However, examination of test data and conditions used herein indicated that individual trajectory generation was generally not necessary since the test-firing procedures usually produced a relatively homogeneous sample of attack velocities and dive angles. In addition, the pilots generally tried to fire in a relatively stable wind condition. These conditions suggested the use of a single nominal trajectory over the homogeneous samples. A further simplification was possible by straight-line approximation of a portion of the trajectory. This enabled use of a fully trigonometric trajectory error transform. Such a simplified, trigonometric, approximation procedure was derived and used in this report. While it could not be as precise as individual trajectory generation, comparative results from the two procedures (some of which are displayed later) indicate that, under certain general conditions, the two trajectory-transform techniques are nearly equivalent.

PROCEDURE FOR A TRAJECTORY-TRANSFORM TRIGONOMETRIC APPROXIMATION

A-4. The trajectory-transform method employed herein used a single nominal trajectory for samples of test data which were relatively homogeneous with respect to weapon system, attack velocity, and relative wind condition at launch. The goodness of the approximation depends on the following assumptions:

a. The angular errors dealt with are generally very small.

b. The attack angles used are not extremely small.

Assumption a. essentially holds for errors of 30 mils or less while assumption b. essentially limits applicable attack angles to about 3 degrees or larger.

A-5. The basic procedure consists of first determining the conventional LOS-transform angular-pitch error and then multiplying it by an expansion factor. The product is the estimate for the trajectory-transform angular error. Specifically, if α denotes an LOS-transform angular-pitch error of an impact (or MPI) about a reference point (the "zero error" point), then the trajectory-transform error, θ, is given by:

$$\theta \approx \alpha \left[1 + \frac{\tan(\Delta T)}{\tan(\gamma)}\right] \qquad \text{(A1)}$$

where γ is the line-of-sight angle from firer to the reference point and ΔT is the average angular difference between the fall angle and the line-of-sight angle.

A-6. To project a trajectory-transform pitch error back onto the ground plane under a given attack geometry, the following steps are performed in the given sequence:

a. $$\theta' = \theta / \left[1 + \frac{\tan(\overline{\Delta T})}{\tan(\bar{\gamma})}\right]$$

where $\overline{\Delta T}$ and $\bar{\gamma}$ are as above but are based on the desired attack geometry.

b. Using the conventional LOS transform under the given attack geometry, project θ' onto the ground. The result is the ground-miss distance associated with θ and the given attack conditions.

A-7. For very small trajectory-transform angular (mil)-pitch error, θ, a quick closed-form approxiation for the associated ground pitch-miss distance, z, is:

$$z \approx \frac{\theta \cdot SR}{\sin(\gamma) \cdot 1019 \cdot \left[1 + \frac{\tan(\overline{\Delta T})}{\tan(\bar{\gamma})}\right]}$$

where SR denotes attack slant range, and $\bar{\gamma}$ and $\overline{\Delta T}$ are defined as above.

EMPIRICAL COMPARISON OF TRAJECTORY-TRANSFORM TECHNIQUES

A-8. The accuracy of formula (A1) was checked against results derived from individual trajectory generations. The latter were performed by Picatinny Arsenal, New Jersey on the ballistic-dispersion pitch errors (σ_3 error) from Phase B of the baseline test. In applying (A1) to the LOS-transform errors (also computed by Picatinny), a single nominal trajectory was used because

helicopter attack conditions were similar over cases. In applying formula (A1), a further approximation was made by applying it to the standard deviation of LOS-transform errors, instead of computing the standard deviation of individually transformed LOS errors, which would have been more accurate. Comparative results are shown in Table A-1. Results from the two trajectory-transform methods generally agree within ± 5 percent. Considering the simplicity of use of (A1) it appears to be a good useful approximation.

TABLE A-1. Comparison of the Trajectory-Transform Approximation with Actual Trajectory Generation

RIPPLE SIZE (No. pairs)	RANGE TO MPI (m)	AVG LOS ANGLE	ΔT[a] (deg)	BALLISTIC DISPERSION ST DEV (mils)		
				LOS[b]	TRAJ APPROX[c]	ACTUAL TRAJ[d]
4	2373	70	4.1	3.73	7.5	7.4
	1737	66	2.3	4.17	6.7	6.6
	1006	67	1.05	5.74	7.3	7.4
	2952	92	6.7	3.97	9.0	9.3
7	2353	71	4.1	3.59	7.2	7.6
	1889	60	2.65	4.14	7.3	7.1
	943	70	1.0	5.06	6.3	6.2
	3018	80	6.95	2.92	7.4	7.0
	2952	92	6.7	3.67	8.3	8.6
19	2354	71	4.1	4.09	8.2	8.3
	1579	78	1.95	5.86	8.4	8.2
	1045	61	1.1	8.45	11.1	10.9
	2896	80	6.5	4.47	10.8	11.2
	3027	89	6.95	4.26	10.1	10.6

[a] ΔT = (Fall Angle – LOS Angle) computed for the tabulated range to MPI from a nominal trajectory determined by: Mk 40 motor-M151 warhead - 90 kts launcher velocity - launch in trim.

[b] Computed by conventional method using line of sight (LOS) derivations.

[c] This entry = (LOS error) $\cdot \left[1 + \dfrac{\text{Tan}(\Delta T)}{\text{Tan}(\text{Avg LOS})}\right]$

[d] Computed by actual trajectory generation.

DERIVATION OF THE TRAJECTORY-TRANSFORM APPROXIMATION

A-9. Figure A-3 diagrammatically represents a trajectory transform in the perpendicular plane and was used in deriving formula (A1). In the figure:

F = firer position
FG = firer altitude
T = point at zero miss distance
GT = pitch axis
TM = ground-plane pitch-miss distance
FT = attack slant range
D = plane perpendicular to FT
γ = attack angle (line of sight)
a = conventional LOS pitch error associated with TM

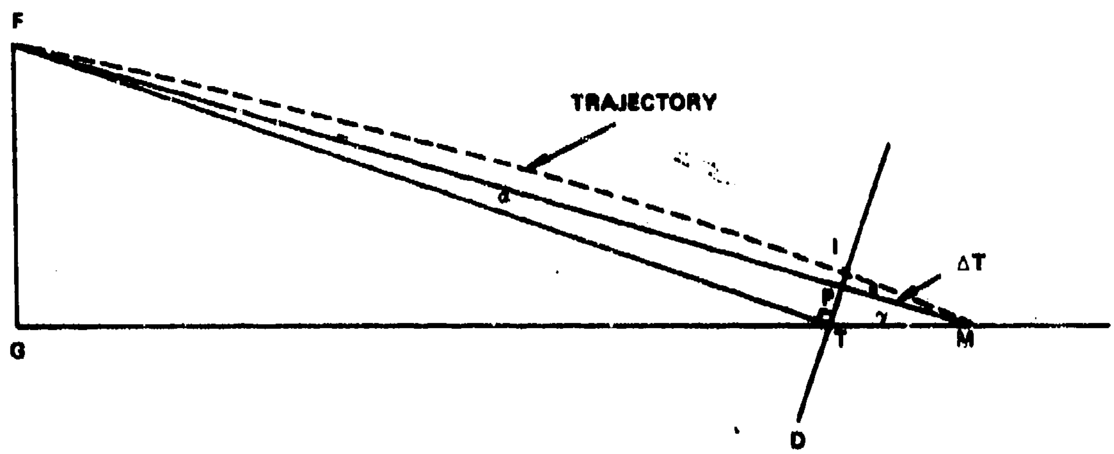

FIGURE A-3. Geometric Representation of the Trajectory Transform of Pitch Error

Under assumption a. (small errors) and b. (attack angles $\neq$ 0) given earlier, and using a rigid trajectory, the following argument holds: The trajectory-transform error corresponding to miss distance TM is denoted by θ. All angles are in radian measure.

A-10. By the definition of trajectory-transform error:

$$\theta = \text{angle subtended by TI} \tag{A3}$$

$$\Delta T + \gamma = \text{angle subtended by TP} + \text{angle subtended by PI} \tag{A4}$$

But the first term of (A4) is the conventional LOS pitch error, which is denoted by a. Also, the second term is approximately $\tan^{-1} \frac{PT}{FT} \approx \frac{PI}{FT}$ since $\tan^{-1} x \approx x$ for small x (radians), and, by assumption a., the errors are small. Therefore, from (A4), there follows:

$$\theta \approx a + \frac{PI}{FT} \tag{A5}$$

Distance PI is then determined by approximating the portion of trajectory from I to M by a straight line, which is valid by assumption b. Then, triangle IPM is, by assumption a., approximately a right triangle. Therefore:

$$PI \approx PM \cdot \mathrm{Tan}\,(\Delta T) \qquad \text{(A6)}$$

where ΔT is the angle formed by IM and PM. Since $PM \approx TP/\tan(\gamma)$ in the figure, it follows, by substitution in (A6) that:

$$PI \approx TP \cdot \tan(\Delta T)/\tan(\gamma) \qquad \text{(A7)}$$

where γ is the LOS angle. Combining (A5) and (A7) yields:

$$\theta \approx a + \frac{TP}{FT}\,\frac{\tan(\Delta T)}{\tan(\gamma)} \qquad \text{(A8)}$$

Then, by the same reasoning as in (A5), since $a \approx \dfrac{TP}{FT}$, it follows that:

$$\theta \approx a + a \cdot \tan(\Delta T)/\tan(\gamma) \qquad \text{(A9)}$$

Since ΔT, the angle formed by IM and PM is approximately the average difference between fall angle and line of sight at slant ranges FT and FM, formula (A9) is equivalent to (A1).

APPENDIX B

STATISTICAL DATA

PILOT EXPERIENCE GROUPS

B-1. The fourteen test pilots and associated test results were partitioned into two pilot experience groups, experienced, denoted by EXP, and nonexperienced, denoted by NONEXP. These experience criteria are the number of rockets previously fired by each pilot. Composition of pilot groups, associated rocket firings, and AH-1G flying experience are shown in Table B-1.

TABLE B-1. Pilot Experience Groups – Phase C Baseline Test

PILOT GROUP	PILOT NAME	FLYING HOURS IN AH-1G	NO. ROCKETS PREV FIRED
EXP	Broeme	1000	15,000
	Johnson	1100	15,000
	Evers	1800	25,000
	Taylor	1600	10,000
	Smithson	1200	7,000
	Schrader	700	10,000
	Walker	850	10,000
	Yarlett	1400	25,000
	Landy	1800	25,000
NONEXP	Struemke	33	90
	Kilker	125	200
	Slocum	30	140
	Nobel	40	90
	Wallace	700	1,200

SAMPLE CATEGORY

B-2. Within each pilot group, the basic sample category was a single pass for a single pilot. For each pilot-pass combination with at least two pairs, fired, a ripple-to-ripple variable-bias standard deviation (σ_2) was computed, along with the associated MPI for the pass. Table B-2 shows resulting estimates for pilot-pass combinations used. Composite accuracy estimates used in the final error budget were formed by pooling appropriate entries from this table.

TABLE B-2. Standard Deviation (σ_2) of Ripple-to-Ripple Variable-Bias (Pair Firings of 2.75-Inch Rockets by AH-1G in Level Flight)

PILOT	EXP/ NONEXP	PASS[a]	NOMINAL RANGE (m)	NUMBER PAIRS	σ_2 (mils)		MEAN MPI (mils)	
					Pitch[b]	Defl	Pitch[b]	Defl
Broeme	EXP	1	2000	4	11.40	8.45	-3.55	-5.60
		2	1000	3	2.76	9.63	2.80	-10.00
		3	3000	4	1.45	10.23	3.85	1.90
		4	2000	4	3.43	12.78	-3.82	3.10
		5	1000	4	6.03	12.04	2.42	5.37
		6	3000	3	3.00	11.83	-4.37	5.07
Johnson	EXP	1	2000	4	2.92	15.01	7.17	-10.22
		2	1000	3	4.61	13.65	7.23	-11.67
		3	3000	4	1.80	7.97	2.55	.30
		4	2000	4	5.16	8.04	9.12	11.10
		5	1000	4	10.47	7.80	6.77	-4.65
		6	3000	4	1.69	9.61	3.37	-4.12
Evers	EXP	1	2000	4	5.42	4.82	3.30	-9.07
		2	1000	4	2.05	11.17	-2.57	-9.95
		3	3000	3	1.77	1.74	4.00	-4.50
		4	2000	4	3.18	13.21	4.62	-19.20
		5	1000	4	8.51	3.04	-2.70	-2.85
		6	3000	4	1.85	4.25	.60	-10.72
Taylor	EXP	1	2000	2	14.49	8.70	-1.35	17.25
		2	1000	4	24.34	11.21	-7.17	20.40
		5	1000	4	13.55	3.89	-.92	5.82
		6	3000	3	7.58	4.48	6.56	2.13
		7	2000	4	5.22	13.95	1.47	-1.85
Smithson	EXP	1	2000	4	7.26	11.06	.57	6.35
		2	1000	4	16.39	3.13	-5.20	6.22
		3	3000	3	3.44	5.06	-1.67	-4.10
		4	2000	4	7.02	7.94	1.90	11.22
		5	1000	4	14.27	5.03	4.20	-1.95
		6	3000	4	2.99	6.58	-1.47	2.32
Schrader	EXP	1	2000	4	1.44	3.76	-1.27	-1.12
		2	1000	3	6.89	1.99	1.50	10.23
		3	3000	4	4.50	6.88	-1.42	-4.67
		4	2000	4	2.04	10.83	-3.97	-7.12
		5	1000	4	8.53	4.07	1.15	-1.32
		6	3000	4	1.57	10.72	-.97	-13.65
Walker	EXP	1	2000	4	9.92	12.02	-5.65	-.40
		2	1000	4	10.88	10.68	-12.45	12.10
		3	3000	3	3.00	6.41	-.27	3.77
		4	2000	2	3.68	5.31	1.10	15.25
		5	1000	4	5.54	7.56	6.32	14.52
		6	3000	2	3.46	3.04	.55	4.55

TABLE B-2. Standard Deviation (σ_2) of Ripple-to-Ripple Variable-Bias (Pair Firings of 2.75-Inch Rockets by AH-1G in Level Flight) (Contd)

PILOT	EXP/ NONEXP	PASS[a]	NOMINAL RANGE (m)	NUMBER PAIRS	σ_2 (mils)		MEAN MPI (mils)	
					Pitch[b]	Defl	Pitch[b]	Defl
Yarlett	EXP	1	2000	3	10.06	19.91	-9.77	8.83
		2	1000	4	31.91	11.55	-15.30	3.57
		3	3000	4	3.80	8.04	-6.15	3.15
		4	2000	4	3.93	5.95	5.30	4.77
		5	1000	4	7.91	21.57	2.40	1.95
		6	3000	4	1.07	4.36	3.82	8.20
Landy	EXP	1	2000	4	2.07	11.68	-10.37	9.72
		2	1000	4	1.22	11.27	-6.20	12.55
		3	3000	3	3.15	6.79	2.37	18.33
		4	2000	4	5.16	5.91	1.10	5.05
		5	1000	4	6.96	17.04	.65	-8.65
		6	3000	4	2.53	4.65	-1.45	12.35
Wallace	NONEXP	1	2000	4	4.02	10.33	5.42	-5.70
		2	1000	3	9.37	6.88	8.20	13.73
		3	3000	4	3.44	6.67	.45	24.92
		4	2000	4	3.59	6.66	14.32	6.50
		5	1000	4	3.15	11.77	7.25	20.72
		6	3000	4	2.42	7.92	.05	35.55
Struemke	NONEXP	2	1000	4	17.20	8.35	-2.97	7.57
		3	3000	3	1.05	5.54	-7.37	4.20
		4	2000	3	13.20	6.14	2.13	15.23
		5	1000	3	5.07	12.91	-5.50	10.13
		6	3000	2	2.33	11.17	8.35	20.10
Kilker	NONEXP	1	2000	2	3.68	.52	10.10	14.45
		2	1000	4	7.03	6.66	9.42	17.32
		3	3000	3	3.83	7.83	.60	22.93
		4	2000	4	2.23	4.84	8.70	17.15
		5	1000	3	17.14	1.43	11.57	25.93
		6	3000	3	2.54	7.74	-4.47	16.70
Slocum	NONEXP	1	2000	2	9.40	11.74	3.35	17.60
		2	1000	4	10.52	9.35	3.70	10.47
		3	3000	2	.99	17.11	-4.80	-11.10
		4	2000	3	.90	9.66	-1.07	8.80
		5	1000	4	6.01	8.73	-12.22	-5.65
		6	3000	4	9.00	23.06	-3.80	-13.40
Nobel	NONEXP	1	2000	4	10.43	12.52	-3.25	29.50
		2	1000	4	6.50	10.13	13.77	14.55
		3	3000	3	4.35	3.85	-1.67	11.83
		4	2000	4	6.96	8.05	1.72	15.55
		5	1000	4	17.10	4.66	-4.22	-8.27
		6	3000	4	5.78	6.93	-1.67	1.32

[a] Passes are numbered in order of execution. Aborted passes and passes with only one pair fired are not tabulated.

[b] Pitch error are in terms of deviations of lines of sight.